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Torbeck, Richard; Bankowski, Richard; Henize, Sarah; and Saedi, Nazanin, "Lasers in tattoo and pigmentation control: role of the PicoSure^(®) laser system." (2016). *Department of Dermatology and Cutaneous Biology Faculty Papers*. Paper 53.
<http://jdc.jefferson.edu/dcbfp/53>

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Lasers in tattoo and pigmentation control: role of the PicoSure[®] laser system

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Background and objectives: The use of picosecond lasers to remove tattoos has greatly improved due to the long-standing outcomes of nanosecond lasers, both clinically and histologically. The first aesthetic picosecond laser available for this use was the PicoSure[®] laser system (755/532 nm). Now that a vast amount of research on its use has been conducted, we performed a comprehensive review of the literature to validate the continued application of the PicoSure[®] laser system for tattoo removal.

Study design and methods: A PubMed search was conducted using the term “picosecond” combined with “laser”, “dermatology”, and “laser tattoo removal”.

Results: A total of 13 articles were identified, and ten of these met the inclusion criteria for this review. The majority of studies showed that picosecond lasers are an effective and safe treatment mode for the removal of tattoo pigments. Several studies also indicated potential novel applications of picosecond lasers in the removal of various tattoo pigments (eg, black, red, and yellow). Adverse effects were generally mild, such as transient hypopigmentation or blister formation, and were rarely more serious, such as scarring and/or textural change.

Conclusion: Advancements in laser technologies and their application in cutaneous medicine have revolutionized the field of laser surgery. Computational modeling provides evidence that the optimal pulse durations for tattoo ink removal are in the picosecond domain. It is recommended that the PicoSure[®] laser system continue to be used for safe and effective tattoo removal, including for red and yellow pigments.

Keywords: tattoo, removal, laser, picosecond

Introduction

The PicoSure[®] laser is a picosecond laser for aesthetic dermatologic procedures, including laser tattoo removal. Research on laser tattoo removal has now reached a critical mass, and there is a large enough body of evidence to discuss the place of PicoSure[®] lasers in this therapy.

In order to appreciate the significant increase in laser tattoo removal in the past 5 years, it is helpful to understand the brief history of the field.¹ Laser tattoo removal began in the early 1960s with the use of argon and CO₂ lasers.² The nonselective nature of these lasers led to significant side effects, such as scarring and hypopigmentation. Advancements in laser technology in the 1980s led to more selective pigment targeting with quality-switched (Q-switched) lasers.²⁻⁴ From that time period up to the present day, nanosecond-pulse-duration lasers have been the mainstays of care in the management of laser tattoo removal. The newest development in the field is that of picosecond pulse durations, which may result in even finer pigment targeting.

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Both nanosecond- and picosecond-pulse-duration lasers are currently heavily utilized standards of care.

Since 1983, Anderson and Parrish's concept of selective photothermolysis has provided the basis for the effectiveness of picosecond pulse durations for selective pigment targeting.⁵ Their theory is based on the concept that a chromophore within the skin can be targeted without collateral damage, by manipulating absorption and pulse duration to less than or equal to the thermal relaxation time (TRT). The TRT is defined as the square of the diameter of the target chromophore in millimeters. As such, their work indicates that the TRT of pigments treated with picosecond lasers may be optimal for minimizing collateral damage to nontargeted areas. This was tested by Ho et al with computer simulations, utilizing graphite ink particle size as the standard of study (range: 10 nm–5 μ m).⁶ From the simulation, the optimal pulse duration for tattoo removal ranges from 10 to 100 picoseconds, based upon the assumption that the pulse should be less than or equal to the TRT, as well as long enough to overcome the tensile strength of the object. Thus, compared with nanosecond pulse durations, picosecond lasers are likely to provide fewer adverse effects, such as scarring and/or hypopigmentation, due to reduced nonspecific targeting.

Although the simulated test of picosecond lasers for tattoo removal did not occur until 2002, they have been utilized for this purpose since the 1990s.^{2–4,7} Investigators have conducted comparative studies between picosecond and nanosecond therapies to determine the most efficient and safe approach.^{7,8} The PicoSure® laser system is one such picosecond laser that utilizes the specifications of 755 nm wavelength with optional 532 nm wavelength; pulse duration of 550–750 picoseconds; energy of 165–200 mJ; and spot size ranging from 2 to 6 mm.⁹ The following review analyzes the available current evidence to elucidate the recommended future use of the PicoSure® laser system for laser tattoo removal.

Methods

A review of literature on PubMed pertaining to picosecond laser use in laser tattoo removal was performed for the period from May 2015 to August 2015. The following terms were searched: “picosecond” combined with “laser”, “dermatology”, and “laser tattoo removal”. Inclusion criteria were as follows: 1) the article is a case study, review of literature, case report, or commentary; and 2) picosecond laser tattoo removal was used or discussed in the article. Exclusion criteria were non-English articles and those that did not utilize picosecond laser as the primary mode of tattoo removal.

Results

The PubMed search for “picosecond” yielded 4,432 articles. Combining “picosecond” with the specific search terms yielded more focused articles, which included “picosecond laser” (1,691), “picosecond laser tattoo” (13), “picosecond laser tattoo removal” (ten), and “picosecond laser tattoo removal dermatology” (eight). Eleven articles met the inclusion criteria and were reviewed for their insights on picosecond laser tattoo removal (Table 1). Eight of these represent studies that listed the laser parameters investigated.^{7,8,10–15}

Ross et al⁷ evaluated the effectiveness of picosecond versus nanosecond Q-switched Nd:YAG (neodymium-doped yttrium aluminium garnet) lasers in terms of tattoo pigment removal in 16 patients. Each patient received four treatments at 4-week intervals under both pulse durations. The tattoo was split into three sections for comparison of efficacy and one control treatment section. The settings for Nd:YAG picosecond domain laser (Model YG501; Quantel Technologies, Santa Clara, CA, USA) treatment were a fluence of 0.65 J/cm², spot size of 1.4 mm, and pulse duration of 35 picoseconds. Alternatively, the settings for Nd:YAG picosecond domain laser (Model NY82-10, Continuum, Santa Clara, CA, USA) treatment were a fluence of 0.65 J/cm², spot size of 1.4 mm, and pulse duration of 10 nanoseconds. On blinded evaluation, there was significant lightening with picosecond lasers, compared with nanosecond lasers, in 12 of 16 patients with treated tattoos.⁷

Herd et al⁸ performed a comparative split-tattoo study of picosecond titanium:sapphire (795 nm) laser versus Q-switched alexandrite (752 nm) laser for tattoo removal in an animal model (albino guinea pigs). The fluences utilized for the picosecond and nanosecond domain lasers were 6.11, 4.24, and 2.39 J/cm², with respective spot sizes of 1.25, 1.5, and 2 mm. Greater clearance of tattoo pigment was seen in the titanium:sapphire picosecond laser-treated areas in two of four surviving guinea pigs. The histologic clearance mirrored the results of clinical clearance, and the increased fluence led to greater pigment clearance.⁸ Izikson et al¹⁰ compared a novel 758 nm alexandrite 500 picoseconds laser with a Q-switched alexandrite laser for treating black carbon tattoos in an animal model (Yorkshire pig). The 758 nm picosecond laser was used in three settings to produce tissue whitening: high (13–16 J/cm², 1.3 mm spot size), medium (6–7.5 J/cm², 1.9 mm spot size), and low (2.5–3.9 J/cm², 2.9 mm spot size). A fluence of 8 J/cm², spot size of 3 mm, and pulse duration between 30 and 50 was used for the 755 nm Q-switched alexandrite laser. After a single treatment, the 758 nm 500 picoseconds laser produced greater tattoo clearance at all

Table I Clinical studies of picosecond laser tattoo removal and novel dermatologic uses

Author(s)	Year	Design	Number and type of subject	Pigment color or target	Clinical end points and patient satisfaction	Adverse effects
Ross et al ⁶	1998	Intratattoo comparison study	16 patients	Eleven multicolored (black, red, and green); five black only	12/16 tattoos with PS showed significantly more lightening than NS	Pinpoint bleeding, edema, hypopigmentation, scarring in NS
Herd et al ⁷	1999	Controlled comparison study	Six albino guinea pigs	Black	Greater tattoo clearance within PS-treated areas in two of four surviving guinea pigs (three spots almost total clearance) than NS	None
Ho et al ⁵	2002	Computer modeling	N/A	Black (graphite tattoo)	Tattoo clearance in 17 patients	N/A
Choudhary ³	2010	Literature review	N/A	N/A	PS identified as the newest development	N/A
Izickson et al ⁹	2010	Comparison study	Two adult female pigs	India ink and iron oxide	All sites greater pigment lightening with PS compared to Q-switched alexandrite (not significant)-blinded scoring	None
Brauer et al ¹⁰	2012	Case series	Ten patients	Blue and green pigment	11/12 tattoos 75% clearance at 1-month follow-up; 12th tattoo required two treatments	Pain (mean pain score for treatment: -1.08 on ten-point scale)
Saedi et al ¹¹	2012	Prospective trial	15 patients	Black and blue	12/15 patients had >75% clearance in one to two treatments; three had 75% in three to four treatments; all 12 patients completed study; 100% satisfaction	Pain (mean pain score: 4.5/10), swelling, postinflammatory hypopigmentation in three of 15, postinflammatory hyperpigmentation in two of 15, blistering
Alabdulrazzaq et al ¹³	2015	Case series	Six patients	Multicolored tattoos that contain yellow pigment	One subject complete clearance in one treatment; five subjects two to four treatments to achieve 75% clearance	Pain (mean pain score: 1.3/10), edema, erythema, pain, blisters (in three of six), transient hypopigmentation (one of six)
Ho et al ⁴	2015	Literature review	N/A	N/A	N/A	N/A
Au et al ¹²	2015	Randomized controlled trial	26 patients	80% blue-black tattoos	81 patients treated with picosecond plus AFR did not experience blistering vs 26 PS alone (statistically significant)	81/95 patients blistered after PS alone; six of 81 did not blister after PS plus AFR
Bernstein et al ¹⁴	2015	Prospective clinical study	21 patients	Black (31), green (eight), red (six), blue (two), purple (two), yellow (two)	Overall average clearance 79% in average 6.5 treatments	Edema, erythema; rarely transient pigment alteration

Abbreviations: AFR, ablative fractional resurfacing (CO₂ laser); NS, nanosecond laser; PS, picosecond laser; N/A, not applicable.

the tested fluencies than the Q-switched alexandrite 755 nm laser.¹⁰ In a series of cases, Brauer et al¹¹ investigated blue and green tattoo pigment removal with a novel picosecond laser. Ten patients representing 12 blue and/or green tattoos were treated with a 755 nm alexandrite laser (Cynosure®). The settings used in the study were fluences of 2.0–2.83 J/cm², with 750–900 picoseconds pulse durations and respective spot sizes of 3.0–2.6 mm. At 1-month follow-up, eleven of 12 treated tattoos showed >75% clearance with one to two treatments. Additionally, two-thirds of the blue-green tattoos approached 100% clearance after treatment.¹¹ In a prospective trial by Saedi et al,¹² the efficacy of picosecond 755 nm alexandrite laser (Cynosure®) for tattoo pigment removal was evaluated. Twelve patients completed the study. The

settings utilized were fluence range of 2.1–4.1 J/cm², spot size of 2.5–3.5 mm, and pulse duration of 500–900 picoseconds. Blinded physician evaluation demonstrated that all 12 patients had a >75% tattoo clearance rate over an average of 4.25 treatments. Nine patients achieved the 75% clearance threshold after two to four treatments. Upon filling out a satisfaction survey, all patients were identified as satisfied or extremely satisfied with the treatment.¹² Au et al¹³ retrospectively investigated the incidence of bulla after tattoo treatment. Eighty-one patients were treated with picosecond domain alexandrite laser alone, and an additional 20 patients were treated with a combination laser therapy of fractionated CO₂ ablation. The settings used for the picosecond domain alexandrite laser alone (PicoSure®; Cynosure,

Inc, Westford, MA, USA) were fluences of 3.09–3.37 J/cm² and spot sizes of 2.94–2.95 mm. The combination therapy of picosecond/ablative fractional resurfacing (AFR) (Fraxel Re:pair; Solta Medical, Inc., Hayward, CA, USA, and AcuPulse; Lumenis Ltd., Yokneam, Israel) used a fluence of 2.67 J/cm² (picosecond), energy of 10–60 mJ (15%–40% coverage; Fraxel Re:pair), and energy of 10–20 mJ (5% coverage; AcuPulse). Bullae formed in 26 patients treated with the picosecond laser alone. In comparison, none of the combination therapy (picosecond/AFR)-treated tattoos developed blistering.¹³ Alabdulrazzaq et al¹⁴ evaluated the use of a novel 532 nm picosecond laser for the clearance of yellow tattoo ink. The case series consisted of six subjects with multicolored tattoos that contained yellow pigment. Laser settings used for the Nd:YAG 532 nm laser were a fluence range of 1.1–1.4 J/cm², spot size of 2.5–3.3 mm, and pulse duration of 450–500 picoseconds. Treatment intervals ranged from 6 to 8 weeks, with one patient achieving complete clearance in a single treatment. All others achieved 75% clearance in two to four treatments.¹⁴ Bernstein et al¹⁵ tested the use of a Nd:YAG picosecond domain laser in multicolor tattoo removal. It was used on 21 subjects, representing 31 tattoos treated. The settings used for the frequency-doubled picosecond-domain laser (PicoWay®; Syneron Candela Corp, Wayland, MA, USA) were fluence of 11 J/cm² for 1,064 nm and 5.5 J/cm² for 532 nm; spot size of 3–5 mm; and pulse duration between 350 and 450 picoseconds (532 and 1,064 nm, respectively). Blinded-scaled evaluation showed an average 79% clearance score after 6.5 treatments. Tattoo pigment clearance varied by color, with black and purple showing most improvement with 1,064 nm after seven treatments. Yellow and red pigments exhibited the highest clearance score of 85% and 80%, respectively, with 532 nm wavelength after seven treatments.¹⁵

Discussion

With the rapid increase in tattooing, there has been a parallel increase in demand for removal.⁴ This has spurred significant growth in the application of laser tattoo removal. For many years, the standard of care was Q-switched lasers with nanosecond pulse durations, but the literature now suggests that picosecond lasers may be a more effective therapy. In comparison to nanosecond lasers, clinical results from picosecond lasers have demonstrated better tattoo pigment clearance and a reduction in side effects. Initial work by Ross et al⁷ identified that picosecond pulse durations can lead to significantly better whitening compared to nanosecond pulse durations, in addition to the need for fewer treatments, with comparable

side effects.⁷ While the mechanism behind picosecond pulse duration laser's removal of tattoos has not been definitively elucidated, it is postulated that photomechanical and thermal damage to the tattoo ink leads to elimination either transepidermally and/or by macrophage rephagocytosis.⁸ It has been suggested that the improved efficiency compared with nanosecond lasers observed by those like Ross et al⁷ is due to the better matching of the pulse duration, less than or equal to the TRT of the chromophore (diameter dependent).^{5–8,10,16} Standard estimations of tattoo particles are 0.1 µm, resulting in a TRT in the picosecond duration.⁶ PicoSure® is one such laser with current specifications of 755 nm wavelength plus an optional 532 nm wavelength; pulse durations of 550–750 picoseconds; energy of 165–200 mJ; and spot size range of 2–6 mm.⁹ Recent studies have supported this line of thinking.^{9,12}

Regarding potential side effects, it is important to point out that picosecond pulse durations allow for inertial confinement, whereby thermal and photomechanical damage are confined to the particle.⁸ Thus, tattoo ink particles can be damaged while the surrounding tissue is not. In addition, picosecond lasers allow for more concentrated energy delivery. As a result, picosecond lasers allow the use of lower treatment fluences.^{8,12} This reduction in treatment fluences decreases adverse side effects, such as posttreatment pigment alteration or scarring. Contrarily, because of their longer wavelength, nanosecond pulse duration lasers allow for the diffusion of thermal and photomechanical (acoustic) shockwaves to the surrounding tissue.^{6,8,12} Adverse events such as scarring were not reported in any clinical study evaluated, but postinflammatory pigment alteration was evident in some patients who received treatment with picosecond lasers.

Perhaps this reduced likelihood of adverse side effects plays a role in patient satisfaction with picosecond lasers. In one study, patients rated treatment satisfaction as high, which was also correlated with clearance.¹²

Conclusion

Tattoo removal by laser systems is an evolving field that has experienced recent major advances in the use of picosecond lasers, including the introduction of the PicoSure® laser. In the few comparison studies available, picosecond lasers are most effective, requiring less treatments and lower fluences than nanosecond lasers.^{7,8} In addition, when measured, patient satisfaction has been rated highly by the patients. Hence, although Q-switched lasers using nanosecond pulses have been stalwarts in laser tattoo removal since the 1980s, recent technological advancements in picosecond lasers

have revolutionized the field.¹² Multiple recent studies have strengthened the argument for using picosecond pulse duration lasers for the removal of tattoos. Picosecond lasers are a safe and efficient therapy model for removal of tattoo pigments, most notably in darkly pigmented tattoos.

Disclosure

All authors have completed and submitted the International Committee of Medical Journal Editors Uniform Disclosure Form for Potential Conflicts of Interest, with the only conflict being that Mr Bankowski is an employee and shareholder of Cynosure. The other authors report no conflicts of interest in this work.

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